Developing a Robust, Adaptable NASA Human Space Flight Strategy
Factoring Budgetary and Technological Uncertainty

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The purpose of this paper is to serve as a **"primer"** for decision makers, leadership and program or project managers on the assortment of ingredients that will define any strategy for advancing human space flight. The factors to consider are presented in a format that simplifies, offering metrics by which to form a basis for a robust, adaptable strategy that takes into account the uncertainty in both technology development and future budgets.

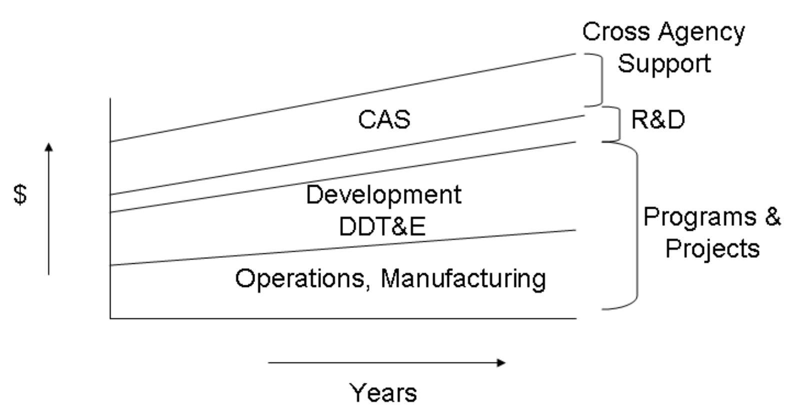
The motivation around this primer is driven by a need to improve communications between cost estimators, operations analysts and program or executive leadership given the complexities of NASA cost structures and the ever changing terminology in finance and budgeting. Additionally, opportunities for improvement are suggested alongside their challenges for NASA and the aerospace industry NASA employs for most of its work.

- **The NASA Human Space Flight Portfolio**

The elements of the NASA Human Space Flight (HSF) portfolio can be grouped into four basic functions.

- Cross Agency Support
- Research & Development
- Future Systems Development
- Operations & Manufacturing

These 4 elements of the HSF portfolio are represented notionally in most of this review, because the simplification should assist with the goal of the review, improved communication and understanding by the reader, while not being so simplistic as to misrepresent a complex and nuanced situation. Notionally then, the NASA HSF portfolio can be represented as follows.



- **Myths, Misunderstandings, and Clarifications**

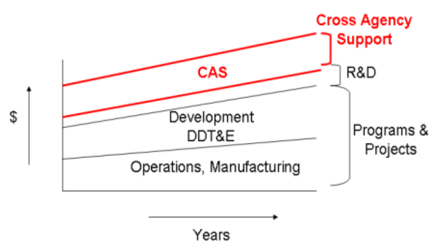
Consider the following statements:

I. High NASA overhead creates large fixed costs for NASA projects.
II. Most of NASA's budget goes to R&D
III. NASA has large fixed costs

Many of these statements, common in discussions among program and project managers, leadership, and cost estimators, are combinations of myths, misunderstandings and misnomers that contribute to poor communication among all parties. We say "overhead", "fixed costs" and many such terms but do not define it to the degree necessary. This means that program manager Joe only believes he is communicating effectively with program manager Jane. Both erroneously believe they are communicating effectively with leadership, and these may all believe, again mistakenly, that they are in synch with executive leadership. Statements such as these have encouraged the creation of this primer, to assist in discussions about budgets, cost estimates and the systemic problems in NASA and its private sector contractors and suppliers.

This primer will return to these statements after providing a review of the four basic functional areas of the NASA HSF portfolio.

1. Cross Agency Support (CAS)

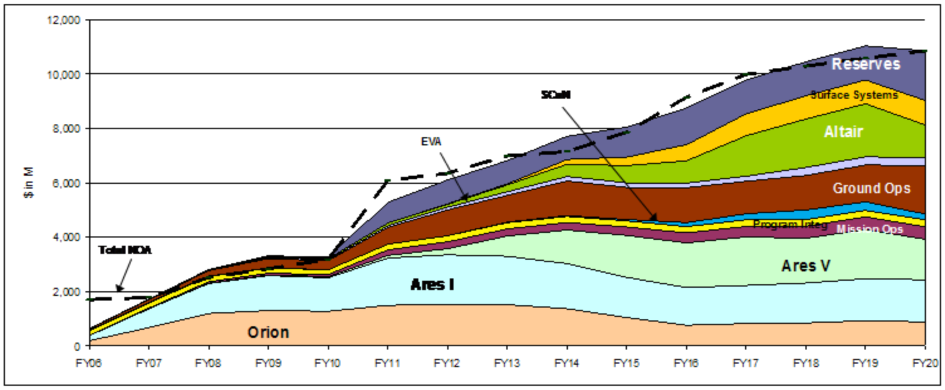


NASA has undergone near continuous change in its accounting patterns for decades, the cause of which will not be explored here. This degree of change may play some role in NASA's failing to pass a clean financial audit since 2002.

> In the enclosed *Report of Independent Auditors*, E&Y disclaimed an opinion on NASA's financial statements for the fiscal year ended September 30, 2005. The disclaimer resulted from NASA's inability to provide E&Y auditable financial statements and sufficient evidence to support the financial statements throughout the fiscal year and at year-end.
>
> *Audit of NASA's 2005 Financial Statements, Office of the Inspector General, referencing the Ernst & Young Audit of NASA Financial Statements, November 14, 2005*

The most recent of these changes in program and project accounting has been to remove overhead costs from programs and projects. Put simply, NASA programs now budget in "direct program dollar accounting", which does not include NASA overhead. The visible effect is that NASA programs and projects are now invariably shown in budget sandcharts **devoid of NASA overhead costs**.

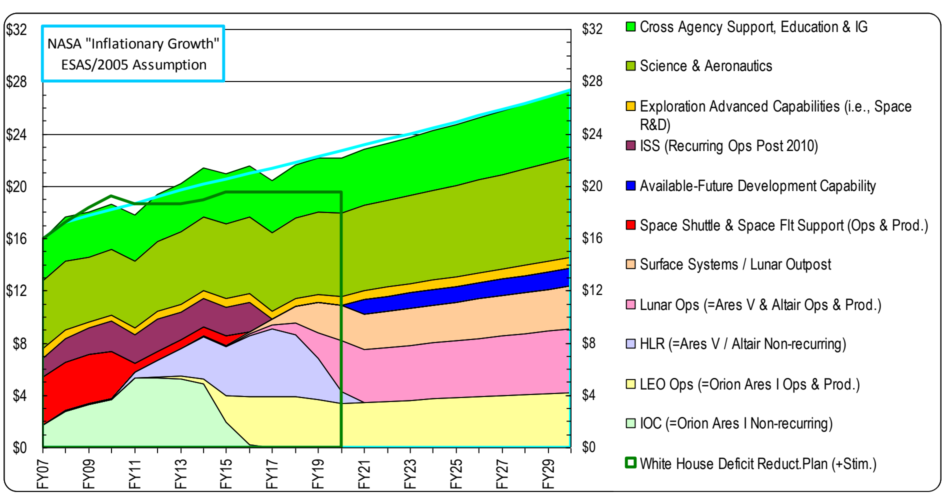
The key term here is "NASA" overhead costs, rather than programs or projects fixed costs, which are a different beast entirely. In other words, traditional “sandcharts” such as the Constellation program example below are essentially devoid of NASA overhead costs. This may seem to be a splitting of hairs, but an understanding of this distinction will be shown as critical to the ability to plan ahead and develop a robust strategy for HSF.



	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	Total
Total NOA	1,707	1,779	2,514	2,840	3,185	6,085	6,346	6,991	7,145	7,856	9,145	9,983	10,294	10,582	10,854	97,306
Lunar Outpost Wedge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reserves	0	0	0	30	45	780	878	854	854	1,104	1,345	1,251	1,251	1,251	1,831	11,454
Surface Systems	0	0	2	4	4	4	14	35	175	315	595	805	854	875	902	4,584
Altair	0	1	13	28	32	90	110	250	451	828	818	1,487	1,781	1,949	1,203	8,840
EVA	12	17	29	37	45	87	100	138	188	171	171	190	294	308	289	2,035
Ground Ops	38	102	199	344	330	817	950	981	1,288	1,181	1,282	1,193	1,270	1,351	1,778	12,881
SCaN	28	21	18	7	0	0	0	20	30	51	148	221	348	311	211	1,412
Program Integration	168	185	190	191	177	209	222	230	224	224	232	248	249	245	281	3,252
Mission Ops	17	25	57	80	75	204	254	280	282	310	382	381	441	457	455	3,841
Ares V	0	3	8	27	42	100	225	748	1,234	1,538	1,848	1,785	1,848	1,818	1,488	12,305
Ares I	188	898	1,108	1,285	1,231	1,734	1,831	1,780	1,858	1,479	1,380	1,400	1,487	1,538	1,552	20,323
Orion	195	878	1,194	1,304	1,279	1,498	1,520	1,521	1,371	1,047	787	827	849	932	884	15,881
Total Cost	641	1,727	2,813	3,317	3,261	5,282	6,104	6,813	7,712	8,049	8,747	9,787	10,451	11,032	10,854	96,589
NOA vs. Cost - Rate	1,066	53	(300)	(477)	(76)	803	242	178	(568)	(193)	398	196	(157)	(449)	0	717
NOA vs. Cost - Cum	1,066	1,119	819	342	266	1,069	1,311	1,489	921	729	1,127	1,323	1,166	717	717	

FY06 NOA includes $247M prior year carry-in; NOA vs. cost reflects forward funding / carry-out requirements

Where is the NASA overhead then, if it’s ***not*** in charts like the one above? In a NASA level sandchart, this larger picture where CAS is drawn out at the NASA level is shown below. To appreciate this function, consider that the bright green “Cross Agency Support, Education and Inspector General” layer below is of a size comparable to the Shuttle program, larger than the International Space Station program, larger in 2009 than the Constellation program, and second in size to the sum of the NASA Science and Aeronautics enterprises.



- Cross Agency Support runs **$3.5B a year**.
- Center Management & Operations (CMO), a sub-category of CAS, close-in at the 9 NASA centers, runs **$2B a year out of the prior $3.5B.**
- The cost of CMO in HSF, that is counting just the four Human Space Flight Centers, Kennedy Space Center, Johnson Space Center, Marshall Space Flight Center, and Stennis Space Center, runs **$1B a year out of the prior $2B.**

1.1 Center Management & Operations

Starting with the largest component of CAS is CMO. At the 9 NASA centers, excluding NASA HQ Washington DC, recent budgets and projections are as follows.

CMO $ in millions	FY09	FY10	FY11	FY12	FY13	FY14
Revised CMO Controls 2-8-08	2045.591	2046.700	2088.000	2155.300	2211.600	2264.700
ARC	150.654	150.825	153.828	158.828	162.984	166.897
DFRC	63.597	63.743	65.020	67.318	69.052	70.709
GRC	182.762	183.203	186.780	192.736	197.867	202.617
GSFC	368.848	370.585	377.201	389.923	400.648	410.268
JSC	365.460	366.834	374.852	385.696	394.872	404.353
KSC	336.419	332.518	338.791	350.257	359.784	368.423
LaRC	222.004	222.452	226.888	234.238	240.307	246.076
MSFC	303.607	304.286	311.385	321.346	329.729	337.646
SSC	52.240	52.254	53.255	54.958	56.357	57.711

Center Management & Operations is an assortment of jobs, most of which would fall into any private sectors definition of “overhead”, areas such as “finance”, “human resources” and “procurement” (which might in the private sector be called “sourcing”, etc). Of note, CMO is not dominated by NASA Civil Servant salaries and benefits, but rather, by contractors. Contractors that support NASA in these overhead functions tend to out-number the civil servants that they work for in these roles by ratios of at least 2, and often as high as 3 to 1. The contractors are “support to the support”.

A NASA centers “CMO” overhead typically includes:

- The Federal / NASA centers “**Procurement**” function, civil servants and their support contractors that develop contracts, competitions, assuring federal acquisition regulations are followed in all contracted activities, etc.
- The Federal / NASA centers “**Finance**” function, an assortment of activities tightly integrated with programs / projects and procurement, everything from receiving funds to disbursing payments to contractors to keeping accounting procedures and so forth.
- The NASA centers “**Human Resources**” function. This is perhaps the most easy match to any private sectors notion of an “overhead” cost, one necessary to the performance of a business but not related to the principal product moving out-the-door per se.
- The NASA centers “**Executive Management**” of the institution, the center per se. This would include all senior management such as a center director and all staff among others.
- The NASA centers “**Environmental Management**” efforts.
- The NASA centers “**Facility Services**” efforts. This item can be as large again as the first few categories, combined.

- The NASA centers "**I/T**" or Information Technology, providing everything from the desktop computers used daily by NASA civil servants to the more complex communications and networks management and associated needs.
- The NASA centers physical "**Security**".
- NASA centers "**Safety and Mission Assurance**" (S&MA) functions.

Notably, the first three prior tasks, Procurement, Finance and Human Resources, have seen a recent consolidation effort to a recently operational NASA Shared Services Center (NSSC). This concept is in keeping with private sector practice to consolidate these types of functions into a single geographical and/or organizational structure, in this case at the NASA Stennis Space Center. The transition, roles and responsibilities still leave portions of related transaction functions at the local centers and this concept continues to mature.

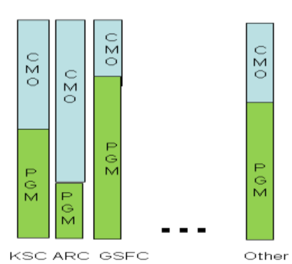
More notable caveats:

The picture of CMO would be too simple if it were simply that they are budgeted separately, called upon when needed, and have no impact to a program of project budget, which would reflect no costs in these subjects. This is not the case.

For one, a full picture of CMO at each center would be required to understand each functional department, its transaction costs when supporting programs and projects, and the transactions between each overhead function itself. This level of detail is beyond the scope of this primer. For example, procurement, finance and a program/projects budgeting are all intimately connected. Though a program may not have to include federal procurement support in its budget, there is nonetheless a cost internal to the program to transact with the private sector through the procurement and finance functions that enable the transaction.

Second, programs and projects have some "direct reimbursable" costs that are paid to CMO and AMO overhead functions. The rules for this are sometimes complex, more akin to negotiations between a program/project and its institution, whereby the CMO overhead support would not have satisfied the requirements of the program or project if left in their most plain vanilla, and "free", flavor. These CMO costs "covered" by a program or project, as part of the CMO amounts shown previously, require a level of detail that is also beyond the scope of this primer.

Third, what any center considers within its generic CMO function can vary, so it should be noted that $365M worth of CMO roles and responsibilities at JSC is not identical in function to the $304M worth of such tasks at MSFC. This breakdown is also beyond the scope of this primer. As shown below, for just the Information Technology function, definitions of "who pays" certain overhead costs are an evolving beast.



These three prior caveats are addressed ahead when considering potential improvements, initiatives, technologies, modern supply chain processes or practices that could reduce CMO costs. A reduction in CMO costs by just 10%, while providing the same or higher level of real support, would free up $200M dollars at the agency level that would be usable by NASA programs and projects. Similarly, for HSF a 10% improvement in CMO at the 4 NASA Space Flight centers would free up $100M yearly for HSF programs and projects. This would be so in a zero-sum game, whereby the budget gain does not cost anything up-front, and where the savings remains in the agency, but it is also so that in a diminishing budget such a savings in CMO can mean a program or project does is not get exposed as much to that diminishing budget.

1.2 The rest of Cross Agency Support, outside of CMO

While the picture above of CMO addresses about $2B of the $3.5B in CAS, a full picture has to address the remaining $1.5B in CAS. As shown below in this current year this remaining cost of CAS is driven by “Agency Management & Operations” (AMO) and “Institutional Investments”.

Cross-Agency Support

FY 2010 Budget Request

Budget Authority ($ millions)	FY 2008 Actual	FY 2009 Enacted	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014
FY 2010 President's Budget Request	**3,251.4**	**3,356.4**	**3,400.6**	**3,468.4**	**3,525.7**	**3,561.4**	**3,621.4**
Center Management and Operations	2,011.7	2,024.0	2,084.0	2,119.2	2,142.5	2,166.1	2,189.9
Agency Management and Operations	834.1	921.2	961.2	956.9	964.5	972.3	981.5
Institutional Investments	325.5	343.7	355.4	392.3	418.7	423.0	450.0
Congressionally Directed Items	80.0	67.5	0.0	0.0	0.0	0.0	0.0
FY 2009 President's Budget Request	**3,242.9**	**3,299.9**	**3,323.9**	**3,363.7**	**3,436.1**	**3,511.3**	--
Center Management and Operations	2,013.0	2,045.6	2,046.7	2,088.0	2,155.3	2,211.6	--
Agency Management and Operations	830.2	945.6	945.5	939.8	950.5	961.3	--
Institutional Investments	319.7	308.7	331.7	335.9	330.4	338.3	--
Congressionally Directed Items	80.0	0.0	0.0	0.0	0.0	0.0	--
Total Change from FY 2009 President's Budget Request	**8.5**	**56.5**	**76.7**	**104.7**	**89.6**	**50.1**	--

Note: In all budget tables, the FY 2010 President's Budget Request depicts the September 2008 Operating Plan for the 2008 Actuals and the 2009 Omnibus Appropriations Act (P.L. 111-8) and the American Recovery and Reinvestment Act (P.L. 111-5) for the 2009 enacted.

The functions accomplished within the prior Billion-plus dollars add significantly to functions that were already covered under Center Management & Operations or CMO, the distinction being:

- AMO costs tend to be “**corporate**” versions of the local CMO functions, the “management of the management”, pulling together the 9 NASA centers to act more cohesively, similarly and thus efficiently.
- AMO includes “corporate” management in the sense that although most functions overlap the previously described more local NASA center functions these tend to be owned at the agency level for purposes of setting overall guidance and accomplishing or enabling some integrating function.
  - For example – AMO includes a Safety & Mission Success Program, a NASA Engineering and Safety Center, Information Technology Security, including

communication systems and network improvements, and funding for Strategic Capabilities Assets, or facilities. Note the similarity to the CMO functions of S&MA, I/T, and Facility Services.

Because of the complementary nature of AMO and CMO, a grand total of about $3.5B a year in an agency budget of about $18B a year, or **nearly 20% of NASA**, is open to initiatives that for every 10% improvement free up about $350M a year. This amount could be used to either build up programs/projects or to remove pressure from the programs/projects under any scenario of budget duress. Improvements here, or that is reduced costs while simultaneously providing equal or greater levels of corporate and institutional services and capabilities, would be the goal. Thoughts on this are expanded upon ahead.

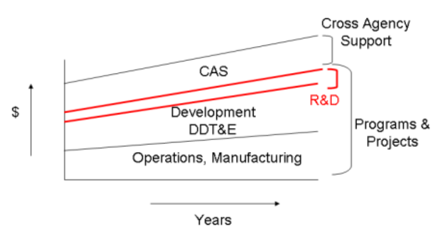
In summary -

The NASA AMO/CMO functions, as vastly complicated as they are, lend themselves to an assortment of improvements that although they may be process reinvention, technological, organizational or regulatory, are not in the same realm as overcoming the difficulties inherent in leaving Earth's gravity well.

10% of AMO/CMO frees up $350M a year for other things.

"More trigger-pullers, and less of everyone else," - General McChrystal's query to his commanders, issued August 7th, 2009.

2. Research & Development



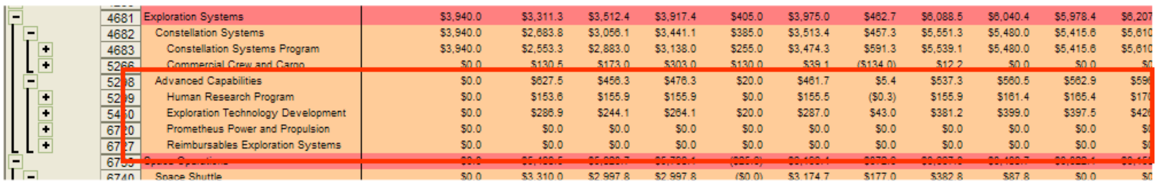
NASA Research & Development is many things to many people. This section will focus on NASA Human Space Flight R&D, with a principal goal of clarifying the term for future use, such as when considering NASA's broader strategic goals. Generally, NASA R&D will be referred to here relative to other NASA programs of higher maturity. This avoids calling all or most of NASA HSF R&D as was once the case - shown below.

Two-thirds of the NASA budget, which excludes the Space Shuttle program and its associated costs, is classified as R&D. NASA's **R&D would total $10.3 billion in FY 2002, $343 million or 3.5 percent above FY 2001, well above both the request and the Senate plan but below the $10.4 billion House total**. Because the Space Shuttle program would receive a large increase, the total NASA budget of $14.8 billion would show a slightly higher increase (up 3.8 percent).

AAAS R&D Funding Update November 7, 2001

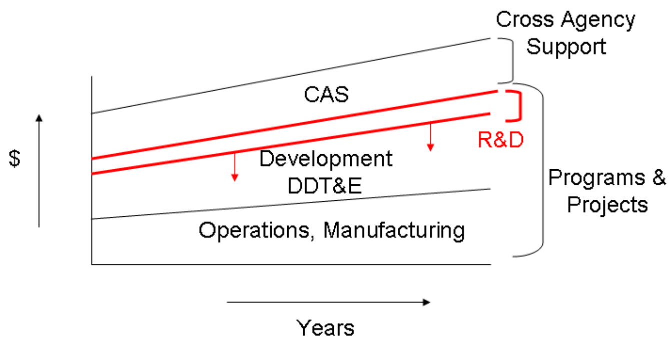
In strategic planning R&D for future space systems can be treated at two extremes – as (1) mission centric technology maturation or as (2) a generic advancement in the fundamentals of human space flight, including operations, living and working in space.

The 2009 Human Space Flight R&D portfolio lies mostly along the first lines of investment, a mission centric approach whereby far term work is assigned resources under Exploration's "Advanced Capabilities".

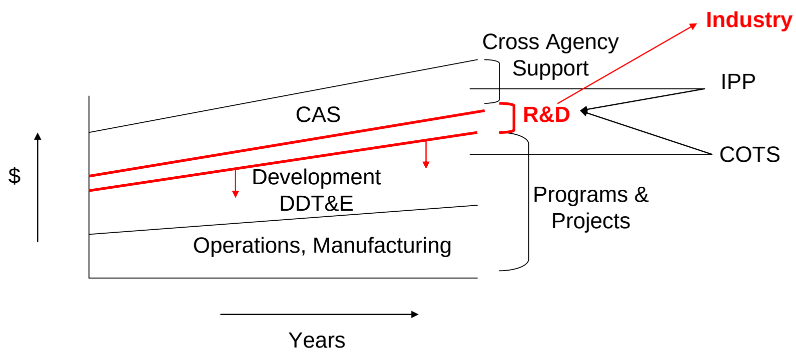


4681	Exploration Systems	$3,940.0	$3,311.3	$3,512.4	$3,917.4	$405.0	$3,975.0	$462.7	$6,088.5	$6,040.4	$5,978.4	$6,207
4682	Constellation Systems	$3,940.0	$2,683.8	$3,056.1	$3,441.1	$385.0	$3,513.4	$457.3	$5,551.3	$5,480.0	$5,415.6	$5,610
4683	Constellation Systems Program	$3,940.0	$2,553.3	$2,883.0	$3,138.0	$255.0	$3,474.3	$591.3	$5,539.1	$5,480.0	$5,415.6	$5,610
5266	Commercial Crew and Cargo	$0.0	$130.5	$173.0	$303.0	$130.0	$39.1	($134.0)	$12.2	$0.0	$0.0	$0
52[illegible]8	Advanced Capabilities	$0.0	$627.5	$456.3	$476.3	$20.0	$461.7	$5.4	$537.3	$560.5	$562.9	$59[illegible]
52[illegible]9	Human Research Program	$0.0	$153.6	$155.9	$155.9	$0.0	$155.5	($0.3)	$155.9	$161.4	$165.4	$17[illegible]
54[illegible]0	Exploration Technology Development	$0.0	$286.9	$244.1	$264.1	$20.0	$287.0	$43.0	$381.2	$399.0	$397.5	$42[illegible]
67[illegible]0	Prometheus Power and Propulsion	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$[illegible]
67[illegible]7	Reimbursables Exploration Systems	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$[illegible]
67[illegible]	Space Operations	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6740	Space Shuttle	$0.0	$3,310.0	$2,997.8	$2,997.8	($0.0)	$3,174.7	$177.0	$382.8	$87.8	$0.0	$0
					2009		2010					

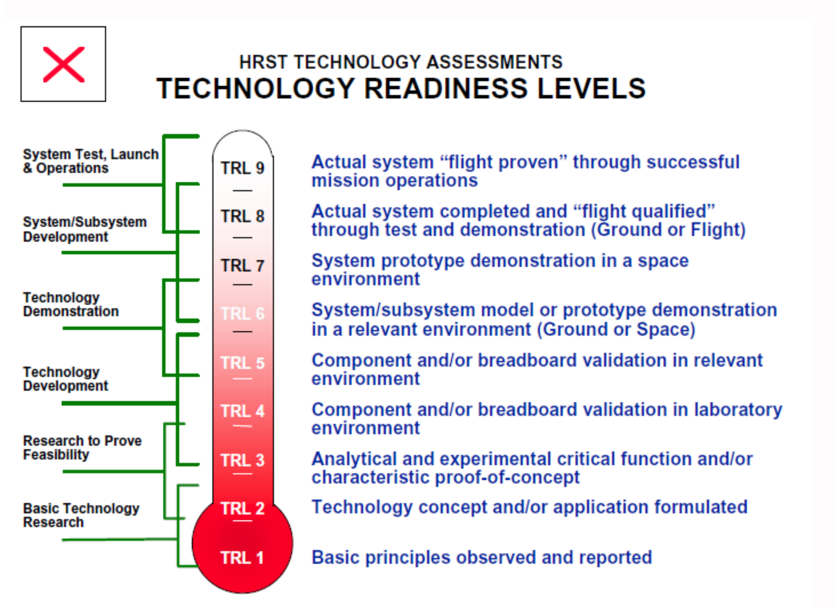
For case #1, mission centric R&D, it would be possible to show the larger picture of HSF represented notionally as follows, where R&D flows it's products to the next product in development only. Here the R&D lies **inside the program/projects** with specific attention to diffusing a product into that specific development program at that time, such as today's Constellation program.



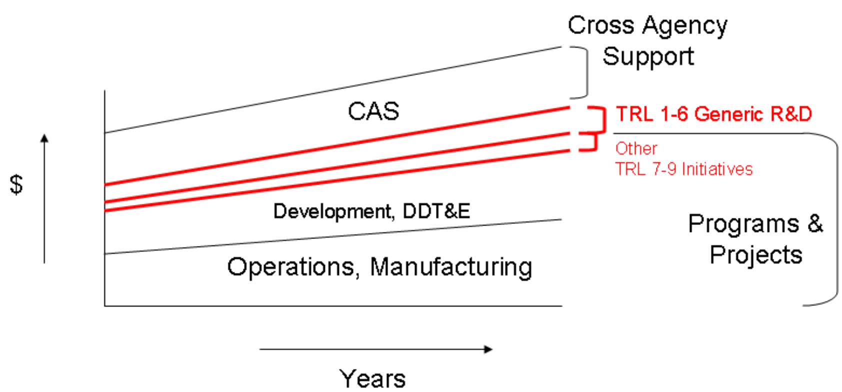
Alternately a strategic decision would be made that invests R&D resources along the framework of case #2, where the R&D is a generic advancement in the fundamentals of human space flight, including operations, living and working in space. Technology maturation for space flight, independent of a specific architecture, would be funded to diffuse knowledge in and out of the organization. This approach would appear as shown originally, apart from CAS, program/projects and operations/manufacturing. Since there are programs within the corporate level of NASA AMO that also invest in fundamental research goals, and there are (or may be) multiple strategic initiatives within a development program oriented around low cost access to space, it would be critical to diffuse knowledge from all these outward to industry. The right approach to efficiently spreading knowledge would be a critical part of such an R&D investment strategy.



These two extremes previously shown are just that, extremes, from which mixtures or hybrid investment strategies can arise. Book-keeping may find that resource allocation is better understood, traceable and managed when classifying R&D using the NASA "Technology Readiness Level" (TRL) scale, with R&D being classified as investments from TRL 1 to 6, and anything above that being the realm of a new development effort, such as Constellation.



Such a TRL distinction for R&D would create a HSF portfolio strategy as shown below. This view accepts that "Other TRL 7-9 Initiatives" are representative of having multiple developments to meet multiple needs. The current Commercial Orbital Transportation Services (COTS), Commercial Resupply Services (CRS) and potential COTS "crew" investments fall along these lines.



In either case #1, #2 or any hybrid, a benchmark on the total R&D resource investment amount is a first strategic decision. Industry benchmarks vary as to the resources spent on "R&D" or work that is free to fail, and more likely than not will – by definition. Most such investment strategies accept that higher risks are necessary when gathering knowledge and the process continues to invest in that work that does succeed using other funds, cutting off the failures, which are part of the process. **Industry values of R&D investment from 5% to 10% are common**, a value which would mean that a HSF portfolio of $9B a year would require an R&D investment of from $450M to $900M a year. More than likely the value would be higher where technology maturity is lower, as in aerospace challenges with affordability and creating safe, routine access and operations to and in space. By way of a benchmark, the highest values of R&D investment occur in “Drugs and medicines” and “Communication equipment” at about 10% of net sales each, shown below.

Company R&D funds as a percent of net sales in R&D-performing companies, by industry and size of company: 1956–98

[Percent]

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	1980	1981	Industry and size of company	SIC code	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
			Distribution by industry																		
.9	2.1	2.2	All industries[1]		2.6	2.6	2.6	3.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.8	3.0	2.9	3.1
A	NA	NA	Manufacturing		NA	NA	NA	NA	3.2	3.1	3.1	3.1	3.1	3.2	3.3	3.1	2.9	2.9	3.3	3.3	3.2
T)	(T)	0.4	Food, kindred, and tobacco products[2]	20,21	0.4	0.4	0.4	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.5	0.4
T)	(T)	0.4	Textiles and apparel	22,23	0.5	0.4	0.5	0.5	0.5	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.9	0.8	0.9	1.1
.7	0.8	0.9	Lumber, wood products, and furniture	24,25	0.8	0.8	0.7	0.8	0.6	0.6	0.6	0.6	0.6	0.9	0.9	0.7	0.6	0.7	1.4	0.9	0.8
T)	1.0	1.0	Paper and allied products	26	1.1	0.9	0.8	0.8	0.7	0.6	0.8	0.8	1.0	1.1	1.0	1.1	1.0	1.0	1.2	1.1	1.0
.2	3.3	3.5	Chemicals and allied products	28	4.0	4.2	4.6	4.9	5.1	5.2	5.2	5.4	5.3	5.3	5.4	6.0	5.1	4.7	5.3	5.3	6.4
.6	2.8	3.0	Industrial chemicals	281–82,286	3.5	3.4	3.8	4.2	4.4	4.4	4.2	4.1	4.4	4.4	4.4	4.4	3.3	3.9	3.7	3.5	5.1
T)	6.1	6.3	Drugs and medicines	283	7.0	7.7	8.2	8.0	8.4	8.7	8.8	8.9	8.8	8.9	9.6	12.5	10.2	10.4	10.1	10.5	10.6
T)	1.9	2.1	Other chemicals	284–85,287–89	2.3	2.5	2.9	3.1	3.3	3.3	3.4	3.9	3.4	3.0	2.7	2.7	2.5	1.4	2.7	2.1	2.5
.6	0.5	0.6	Petroleum refining and extraction	13,29	0.8	0.7	0.7	0.9	1.1	1.0	1.0	0.9	0.9	1.0	0.9	0.9	0.8	0.7	0.7	0.6	0.8
T)	(T)	1.9	Rubber products	30	1.7	1.7	1.9	1.8	1.7	1.6	1.7	1.9	2.1	2.3	2.3	2.1	2.3	1.6	1.8	1.4	2.1
T)	1.3	1.4	Stone, clay, and glass products	32	1.7	1.9	1.9	2.3	2.4	2.5	2.0	1.8	1.7	1.6	1.6	1.5	1.5	1.5	1.2	1.8	1.4
.5	0.5	0.6	Primary metals	33	0.8	0.8	0.9	0.9	1.0	0.9	0.7	0.7	0.8	0.8	0.6	0.7	0.6	0.5	0.6	0.6	0.6
.5	0.5	0.6	Ferrous metals and products[4]	331–32,3398–99	0.6	0.6	0.6	0.5	0.7	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.3	0.3	0.4	0.6	0.5
.6	0.6	0.7	Nonferrous metals and products[4]	333–36	1.3	1.2	1.2	1.4	1.5	1.3	1.0	1.0	1.2	1.2	0.7	1.2	0.9	0.7	1.0	0.6	0.8
.0	1.2	1.3	Fabricated metal products	34	1.2	1.3	1.4	1.4	1.4	1.2	1.1	1.2	1.1	1.2	1.1	1.1	1.0	1.1	1.4	1.5	1.4
.2	4.5	4.6	Machinery	35	5.0	5.4	5.8	6.7	7.3	7.1	6.8	7.3	7.2	7.5	7.3	4.5	3.8	3.6	5.1	5.6	5.1
.1	10.4	10.1	Office, computing, and accounting machines	357	10.4	10.0	10.5	12.4	12.4	12.3	11.2	13.1	14.4	14.9	13.7	9.8	7.9	8.1	9.9	9.2	9.2
.0	2.2	2.3	Other machinery, except electrical	351–56,358–59	2.4	2.4	2.5	2.6	2.9	3.0	2.8	2.6	2.3	2.9	2.9	2.5	2.5	2.4	2.9	3.0	3.1
.6	3.9	4.2	Electrical equipment	36	4.4	5.0	4.5	4.8	5.1	5.4	5.3	5.2	4.5	4.3	4.0	5.4	5.2	5.4	6.1	5.7	6.6
.7	2.7	2.7	Radio and TV receiving equipment	365	3.3	2.9	3.7	4.3	3.6	3.2	2.4	1.8	1.6	1.0	0.6	4.0	1.0	1.6	2.0	2.6	2.9
.0	5.4	6.0	Communication equipment	366	6.7	7.2	5.1	5.4	5.2	5.5	6.1	6.8	6.1	(S)	7.0	10.1	10.3	8.0	8.5	8.0	11.2
T)	5.9	5.7	Electronic components	367	5.2	6.6	6.6	8.2	9.2	8.5	8.0	7.7	7.4	7.2	7.0	7.8	7.3	8.0	8.5	8.1	8.4
T)	2.5	2.8	Other electrical equipment	361–64,369	2.3	2.6	2.2	2.0	2.2	2.6	2.3	2.3	2.2	2.2	2.1	2.3	2.1	2.5	2.6	2.7	2.8
A	NA	NA	Transportation equipment	37	NA	NA	3.3	3.4	3.6	3.4	3.5	3.5	3.4	4.0	4.2	3.9	3.7	3.6	4.1	3.8	2.5
.2	4.2	3.9	Motor vehicles and motor vehicles equipment	371	4.0	3.5	3.0	3.1	3.3	3.4	3.4	3.7	3.7	4.1	4.0	3.7	3.4	3.6	4.2	3.8	2.2
T)	0.3	(T)	Other transportation equipment	373–75,379	0.7	1.7	2.0	2.3	2.7	2.5	2.6	2.5	2.1	2.1	2.1	1.9	1.2	0.9	1.2	2.2	2.3
.5	3.8	4.2	Aircraft and missiles	372,376	5.1	4.1	4.0	3.9	4.0	3.6	3.9	3.3	3.1	4.0	4.7	4.7	5.3	4.2	4.5	3.9	3.3

See explanatory information and SOURCE at end of table.

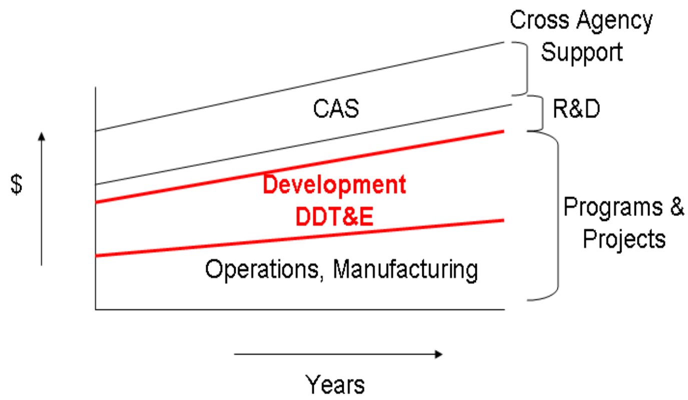
In summary -

The NASA HSF R&D function is among the first decisions in any HSF strategy, taking some amount off the top, continuously, for goals near and far.

The second choice in the R&D investment decision is the characteristic of the portfolio.

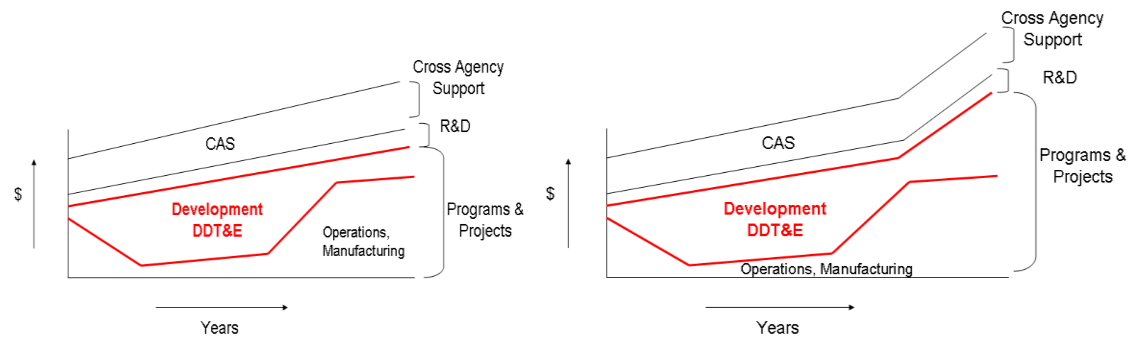
Current HSF R&D 2009 as a % of total HSF = 5.4%

3. Future Systems Development



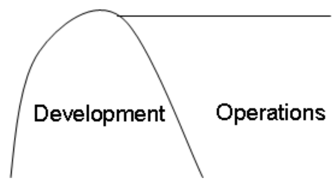
Notionally, a "development" activity can be shown to be continuous as in the figure to the left. It has no disappearing act once a system becomes operational, as it simply moves to develop the next big thing, the next model year, etc. Strategically this transition is dependent on two variables – (1) the resulting recurring cost of the operations and manufacture of the delivered system and (2) the size of the total budget. For a large future budget the recurring operations and manufacturing of the delivered system, the Constellation architecture by way of example, can be high, as added budget will then exist to turn towards the development for any future needs. Inversely a reduced resource in the future, if expected, would not tolerate a high recurring cost for a newly developed system as this would eat out of R&D or subsequent development. At sufficiently high recurring costs and sufficiently constrained top-line resources eventually a high enough recurring operations and manufacturing consumes the entire top-line. This would be un-sustainable long term.

This can be seen as shapes - a shift that diverts Shuttle operations and manufacturing resources to a development, in this case Constellation, that then has a higher recurring total cost, could appear along either of the notional shapes below, depending on the budget beyond the horizon of current planning.

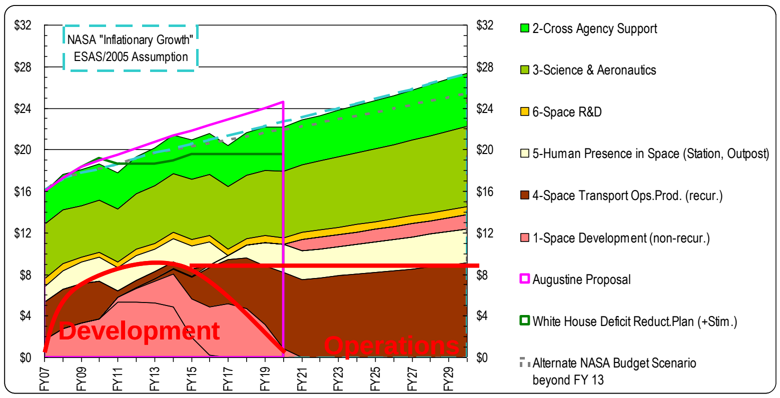


Scenario 1 (left), a development yielding a more expensive recurring operation/manufacturing product in a capped top-line growth, and Scenario 2 (right), a development yielding a more expensive recurring operation/manufacturing product in a top-line that grows to accommodate the added expense. Scenario 1 changes proportions in the portfolio for each item. Scenario 2 preserves proportions.

Notably, the development "shape" in Scenario 1 above is inter-changeable with a view of a development that yields a product at some operational cost similar to the peak of development. This might seem possible, as shown below, in a private sector enterprise where the success of the product yields revenue greater than that which the enterprise had at its inception. But that is consistent with Scenario 2 above – only - and where added revenue does not result it reverts to Scenario 1, which has dramatically reduced the capacity for further product development (not desirable or sustainable).



This prior behavior is seen in real terms viewing a NASA multi-decadal outlook using real data. Note in the figure that follows that amount leftover for future product development in HSF in the 2020's, here dependent on a transition from the International Space Station, one operational system, into any effort in new product development.



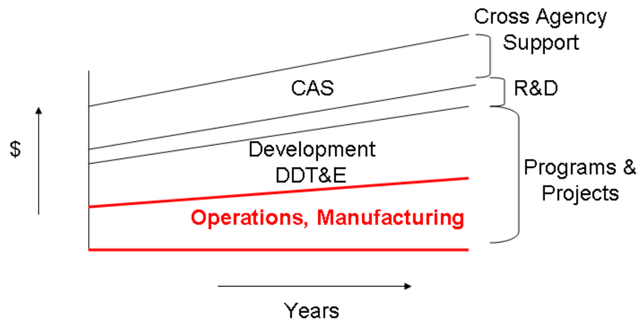
3.1 Robust Planning for Human Space Flight Investments under Uncertain Circumstances

Because top-line budget scenarios can not be guaranteed, any planning in future developments must be robust to uncertainty - using a Human Space Flight beyond-Earth-orbit capability as an example. Uncertainties, to name a few, include:

- Top-line budgets any year in decadal outlooks, actual vs. planned
- Technology maturation, readiness vs. planned
- Cost and Schedule uncertainty, planned costs and schedule vs. actual

Content, overhead, fixed costs and other concepts within this uncertainty will be explored ahead, by looking at the current Human Space Flight enterprise operations and manufacturing as one basis for a future system development.

4. Operations & Manufacturing



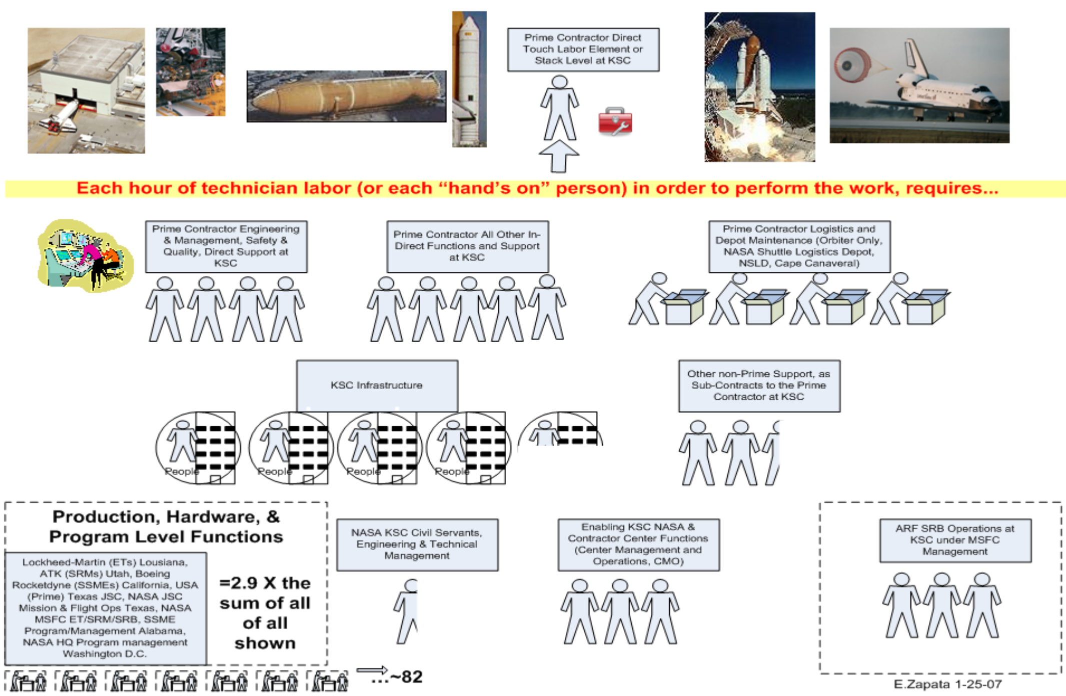
The area of NASA "overhead" costs, as applies at the 4 HSF centers, of NASA HSF R&D investments in the agency, and of future development, such as in the current Exploration program have all been reviewed to here.

Entering into the recurring operations and manufacturing of a current program such as the Shuttle or the International Space Station will further clarify the widely used terms "fixed costs", and the terms "overhead" once again, in this vein referring by size mostly to a contractors capabilities. The prime contractor overhead costs here are DISTINCT from the NASA overhead costs within Cross Agency Support reviewed previously.

- Most of the resources in Human Space Flight have nothing to do with the actual hands-on work, touch labor, of preparing a launch vehicle for launch.
- Most of the resources in Human Space Flight, about 90%, are contractor.
- Contractors in Human Space Flight are contracted by the government within either manufacturing or operations cost profiles that have between 75% and 100% fixed costs; that is, the contractor's costs vary little with flight rate within a narrow band of flights per year in the case of the Shuttle.

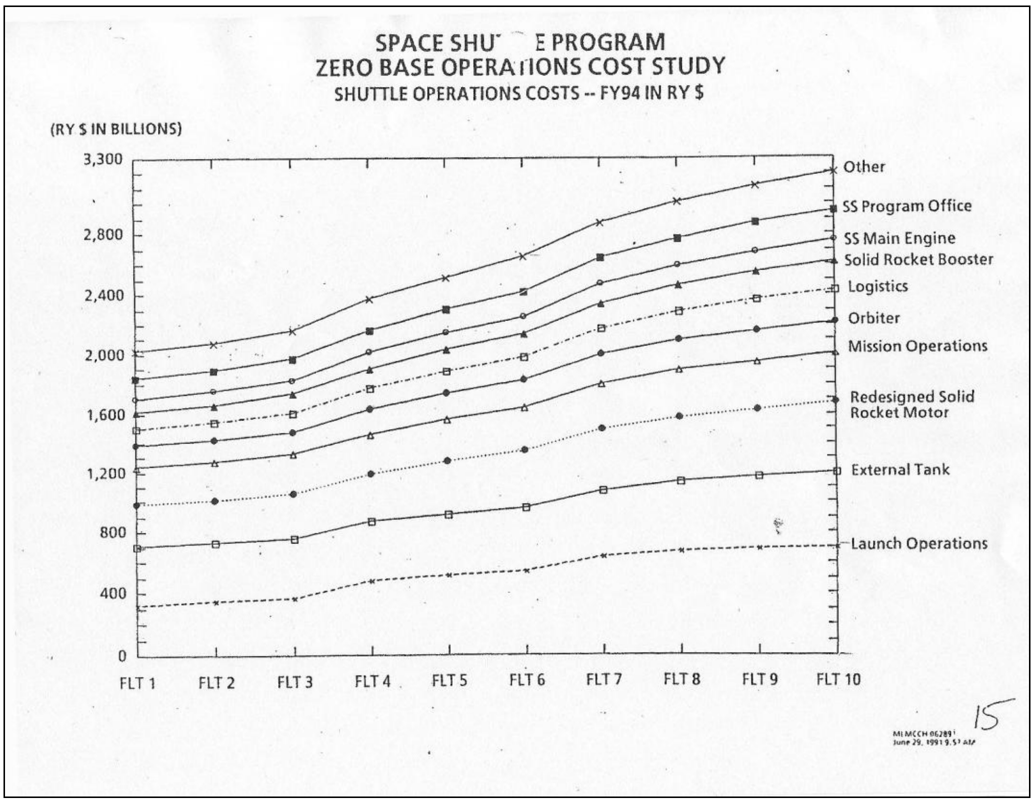
This state of affairs is represented below.

The Current Human Space Flight Launch & Landing Operational Supply Chain



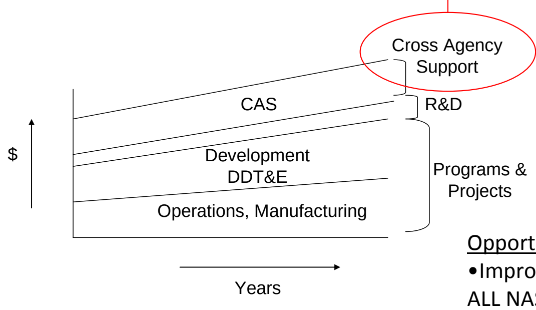
There is more “touch labor” involved, of course, in manufacturing parts for Orbiters, making new External Tanks (ET), making or re-filling Solid Rocket Motors (SRM) or refurbishing and making solid rocket booster (SRB) assemblies. In the figure above this would be in the lower left. In addition there is the very hands-on work of the mission and flight operations at Johnson Space Center. Nonetheless, the ratios between categories of work that are “touch” or “close in” vs. those further removed, that are enabling of such work, tend to be on the order or 10’s and 20’s to 1’s depending on the narrower scope of any effort that’s focused on. One person’s material is another person’s labor. If you are awaiting External Tanks it’s all a material cost, something you “sourced” or “procured”. If you are the maker of External Tanks, then your view is it’s mostly labor, and a little material costs. This happens throughout the categories, as well as if narrowing to a single contractor such as United Space Alliance (USA) or a single function such as Mission Operations.

A key to understanding the behavior of this HSF cost category comes from studies in the mid-90’s that are still supported today establishing the fixed cost nature of the contractor and government functions in a program such as the Space Shuttle. Note that the cost of just 1 launch is about 75% of the cost of 6 launches, hence the term “**fixed costs**”. One launch is not 1/6th of 6 launches, and for that matter zero launches are not zero costs.



5. Summary of HSF Costs, Terminology, Opportunities and Challenges

After this review certain terms become appropriate to certain areas of NASA human space flight cost. With this come certain opportunities and challenges. These follow in the order in which the areas were reviewed.



Proposed Terms for Lines of Communication

- **NASA "overhead"**
- Corporate
- Institutional, Local, NASA Centers
- Administrative
- Base Infrastructure
- Basic, Enabling
- "Contractors supporting NASA support"
- "Agency fixed overhead costs"

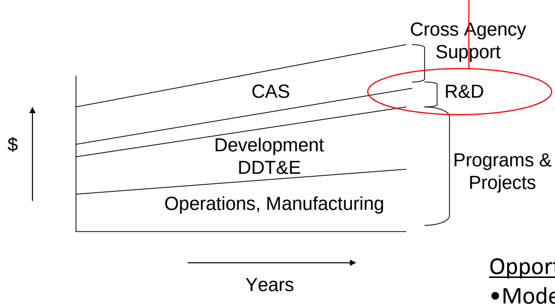
$ 3.5 Billion at the agency level
1 Billion at the 4 HSF Centers

Opportunities

- Improvements benefit ALL NASA programs and projects by freeing funds
- Sizable ("go where the money is")
- Similar, apt for Integration, Consolidation
- Many modern Supply Chain Management (SCM) processes and practices apply

Challenges

- HSF can not just improve on these at the HSF centers alone, as changes here affect all NASA centers ways of doing business
- Requires data for benchmarking
- Determining Return-on-Investment (ROI) to filter new business initiatives



Proposed Terms for Lines of Communication

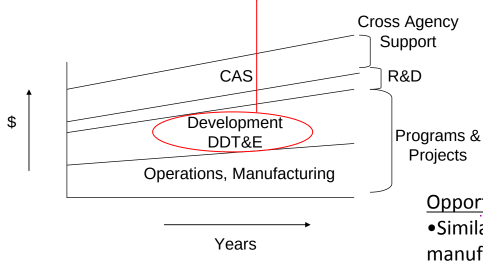
- Technology Readiness Level (TRL)
- **TRL 1-6 = Space Systems R&D**
- Space Systems for-
  - Transportation to and from Space
  - In-Space Systems
  - In-Space Operations
  - In-Space Habitation
- Mission Centric and/or Architecture Dependent and/or Generic, Fundamental

Opportunities

- Modern information technology to apply to large data sets and multi-variable problems
- Executive dashboards, investment methodologies et al

Challenges

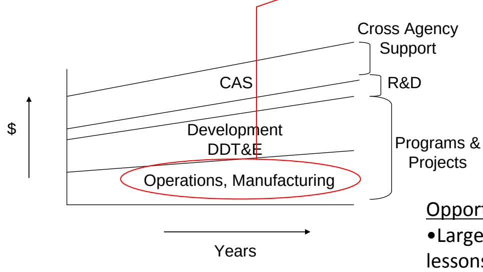
- Spreading results, knowledge
- Balancing the portfolio
- Portfolio management for balanced diffusion of results outward to users
- Integrating any HSF R&D portfolio with other R&D at the center or corporate levels



Proposed Terms for Lines of Communication
- Systems Development
- Design, Development, Test & Engineering
- Non-recurring
- Capital expenses
- One-time expenses
- Sunk costs
- **NASA/Private Sector Development Flexibility & Adaptability**
- Fixed Costs of Development
- Manufacturing / Production Setup

Opportunities
- Similarity to manufacturing & operations if the new product has a heritage to a prior product
- Learning curve
- Lessons learned, data, from prior products, Shuttle, Station

Challenges
- Innovation, departing from the known
- Adaptability, to changing needs
  - Attention to "ilities" – affordability, low cost, reliability, safety rather in balance with performance



Proposed Terms for Lines of Communication
- Recurring Operations & Manufacturing
- Yearly expenses
- Fixed Cost of Operations & Manufacturing
- Manufacturing / Production Capability
- **Contractor Fixed Costs**
- Contractor Variable Costs
- Contractor Infrastructure
- Contractor Overhead

Opportunities
- Large data set and lessons learned, ready to be mined
- Learning curve, experience
- Feedback loop to any new direction, development, or architecture

Challenges
- Efficiencies, fixed costs
- Safety
- Limited providers, contractors, lack of competition opportunities
- Details delegated to the contractors, little customer insight into processes, costs and opportunities for efficiency

6. Supply Chain Management Strategies for Improvement

A supply chain management perspective is taken here as an appropriate response to the structure that has arisen in NASA centers, NASA's largest contractors, and NASA programs. Four of NASA's 10 centers have an emphasis in Human Space Flight, in 4 different states. NASA's liquid stage production capacity, the Michoud Assembly Facility (MAF) is run by the United State's largest Defense contractor, Lockheed-Martin, in a Government-Owned-Contractor-Operated (GOCO) arrangement. The production, refurbishment and refilling of Shuttle solid rocket motors (SRM) is accomplished by ATK Inc. in Utah. A large NASA program such as Shuttle, the International Space Station or Constellation consists of assorted "levels", where program management layers become projects that deliver and receive products from each other. The NASA cross agency support function is ultimately a series of departments that deliver products, much of it information, among each other and to internal programs. Insight into the suppliers to the larger contractors fulfilling NASA contracts generally stops at the larger contractor, which view the primes as the customer.

Chief characteristics of these current NASA and industry structures, and the reason a supply chain management perspective is provided here in considering potential improvements, include:

- **Sub-optimization**:

In the interest of breaking a task down to its smaller, more easily managed and more defined steps or pieces, a hierarchical structure is defined. From this definition assignments are made and resources are assigned to new or existing organizations. The NASA "work breakdown structure" is the clearest form of this hierarchical definition and approach to organizing work. Unfortunately, each of the smaller parts, units or functions (the terms vary) can easily end up being run with only an eye toward its own needs and objectives. While this approach can provide strength, focus for example, it can also devolve into sub-optimization, whereby every part of the job is working so intently with an eye on its own prosperity, with resources coming to be seen as something to defend, that the best interests of the larger task become secondary or neglected.

Supply Chain Management techniques address such over-compartmentalization that results in sub-optimizing the larger goals of the organization by focusing on the definition of functions, collecting data on the resources of these functions, and providing a basis to re-engineer processes. Rather than break the problems down into small pieces, SCM returns to basics of who does what, with what resources, and what is the leanest process to get from A to B.

This process perspective is especially important in bureaucratic organizations where most processes from end-to-end may never have been fully drawn out and connected to measurable outcomes. Before automating any process, a SCM perspective on processes, then resources, leading to feedback loops and desired outcomes, offers a methodology to fully understand problems and opportunities.

- **Long, Complex Supply Lines and Inefficient Communication:**

Once processes and resources are better understood there is the system by which parties in a process communicate in adaptive ways. New information results in a feedback loop whereby improvements or corrective action are enabled. With exceedingly long supply lines this becomes extremely complex. Traditionally NASA purchases most of its goods and services and large contractors manage the lines of suppliers of still more goods and services down the chain. Feedback loops become inefficient as customer and supplier relationships become defined by negotiations and contracts that weaken the lines of communication by which a network of information, materials, services and requirements must flow.

Supply Chain Management techniques address these trends toward obscuring information, insight down the supply chain, and metrics by offering assorted practices that open up lines of communication. A productive supply chain relationship emphasizes a final customer, which is usually not the contracting party. For example a car dealership is the not the true customer of a car manufacturer. With a properly defined customer emphasis, numerous practices in integrating information flows, sharing information in both directions, in automated fashion using modern information technology, become possible and productive. Rather than seeing the sharing of information as a way in which either a contractor or a government entity can seek advantage of each other, the sharing becomes a means by which the integrated enterprise –NASA/contractor- can best meet customer requirements. That customer may be the payload, the science community or a space station, by way of example. An improved supplier relationship management approach grows the relevance to customers that the enterprise seeks to fulfill.

- **Technically Focused, Research Oriented:**

In departments that are technically focused or research oriented many variables in a product development, operation or manufacturing can fall by the wayside. Cost can be neglected to the degree it is seen as merely an output, a consequence of satisfying requirements received from on-high, from some other department. Product reliability, safety, productivity and long term ownership costs can fail to be understood, stemming from the sub-optimization and long lines of communication that result from a breakdown structure approach to problems and products.

Supply Chain Management techniques focus on metrics and offer an excellent way to further understand the variables that are often lost in merely meeting specifications, weight, mass or some related performance requirements. If the goal is “perfect order fulfillment”, an example end-user reliability metric, then an end-to-end perspective that sees the reliability from the point of view of the end-user assures that overly compartmentalized views of this variable feed into the bigger picture.

The prior SCM opportunities can be applied to the Human Space Flight areas presented in this primer.

In CAS:

For the NASA support (“overhead”) functions previously outlined a tremendous number of private sector efficiencies are likely applicable starting with the engineering of processes around customer outcomes. Here the customers are programs and projects, large and small, as this CAS function provides critical support to enable the missions assigned to centers, programs and projects. Initiatives such as the move of the NASA financial systems to SAP, under one consolidated system, or to the NSSC concept, are the start of implementing private sector concepts in the search for efficiencies and improved support to customers. Yet these are merely a start at what is possible in this area.

Ultimately improvements here can take two paths –

Productivity: Assuming a constant resource, can CAS provide more and better support to programs over time. An example there is more processing more contracts, faster, or providing I/T support to new program requirements faster, yet within existing resources.

Costs: Individual initiatives would show how a CAS cost today of $3.5B a year, upon implementing a change, a new approach or practice, or new technology, yields less cost in the future.

SCM improvements in CAS must end-up as agency wide initiatives by definition, but they need not start that way. Human Space Flight centers can lead the way in prototypes, pathfinders, studies, business case development, defining returns on investment, and so on, before any CAS initiatives roll out agency wide. Large HSF programs have an advantage of scale and time in interacting with CAS that smaller programs / projects do not, allowing numerous approaches to be surfaced, tried, re-directed and refined, while having the continuity with which to develop metrics. This adaptive approach can surface what works while avoiding large commitments before gaining knowledge.

In HSF R&D:

For the NASA HSF R&D functions, here used in both the low-TRL sense and the program-mission-centric definition, there are numerous challenges where a supply chain management methodology can add value. While large programs/projects contract to large contractors and these contractors access the market of suppliers, the equation for innovation is quite different when R&D funds seek sources of supply. The R&D funds may remain in-house, that is local to a NASA center and its local sub-contractor support, they may go to larger prime contractors, often manufacturers, some may go toward end-user needs, such as in operations or infrastructure, and lastly some may go to suppliers farthest down in the technology supply chain.

In modern supply chain management practice the R&D of an organization is strongly linked to customer requirements. While the role of I/T is still being defined in translating customer requirements and coordinating R&D, there is a need to balance current vs. new customer requirements as well as where the innovation lies inside the supply chain. An example of a new customer lies inside the notion of low cost access to space. An example where an innovation occurs refers to if the R&D responds to the supplier, the integrator/manufacturer or the end-user/operator needs. In all these matters of balancing a portfolio there is a need for metrics, understanding how the innovation flowed into products, and feedback loops – ideally suited to modern supply chain methodologies.

In Development, Industrial Manufacturing and Operational Programs:

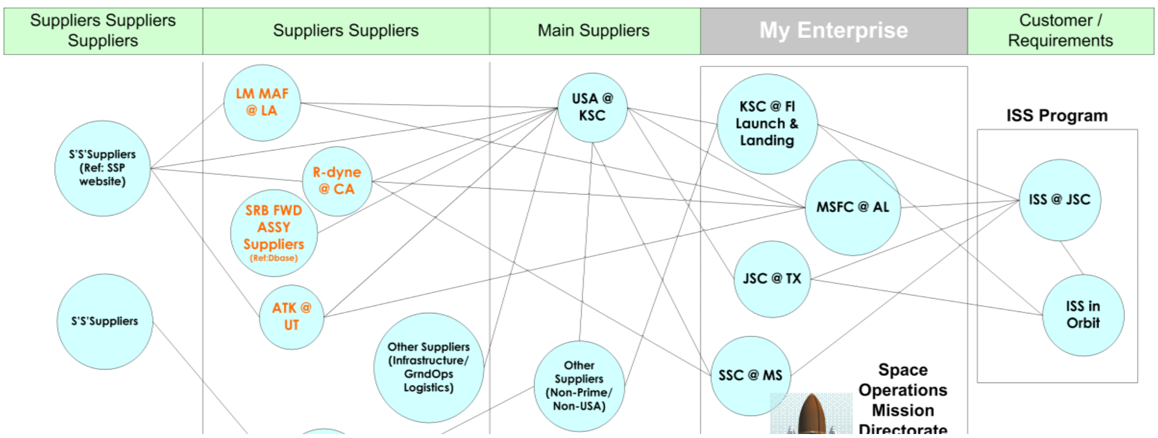
For the NASA HSF development and operational programs there are two major thrusts for improvements that have a supply chain management basis. First, there is the program/project, which must procure goods and services. Second there are the large contractor entities that fulfill requirements. These can not be easily separated not should they be.

A prime contractor in development or operations carries out functions from the most in-direct to the most direct. In-direct functions start with every form of requirements management, configuration control of documents and hardware, document generation and maintenance, asset management, scheduling across all levels, engineering management, quality controls, logistics, sourcing, finances, supplier management, operations and maintenance of assigned or owned infrastructure, readiness reviews, delivery reviews, launch reviews, and so on.

Simply put, all these functions flow information that permits the flow of material.

The information flow between a contractor and the programs/projects further permits the direct function of assembling, manufacturing, launching and hands-on work that is the most visible end-item for a customer.

The Space Operations Supply Chain "As-is" Space Shuttle as a Relationship Network of Enterprises – These exchange Materials or Information



A principal barrier to a more efficient and effective supply chain in a NASA program (such as the development of a replacement for the Space Shuttle, or the development of a means to get crew to the ISS, or the development of a launch vehicle capable of access for crew beyond low-Earth-orbit), lies in the supplier relationship that has emerged in NASA over decades. The current supplier relationship is one where programs and projects have "primes", or in any case the largest contract under any project, even when performing project management and integration at any NASA center. The large contractor relationship is defined by a contractor that sees NASA as the customer and a Human Space Flight enterprise that sees a contractor as a delegate or designee that has promised to fulfill certain requirements in line with certain costs. NASA generally has no insight into the contractor outside of this well defined and contracted relationship.

In a SCM perspective the program or project is not a customer. The customer lies ahead, requiring access to space, crew at the ISS, or in a notional sense a series of goals. Both the NASA program and project in a SCM view have this as their one-and-the-same customer. In this SCM view NASA has insight into the contractor production, costs, processes, suppliers, and many other metrics. These are not proprietary or concealed. In this SCM view the inverse also applies, and the contractor has direct access to flows of NASA program/project information that are also traditionally obscured or suffer from delayed, translated, official or sanitized updates, such as inventories, schedules, resources and requirements. These improved SCM forms of "direct" access are controlled by each party, not awaiting permissions or delayed translations from the other.

Appreciating that the levels of integration that occur between large companies and their suppliers in the private sector are likely not possible when describing the opportunities for such integration between a government agency, it's programs, it's federal regulations and procurement rules and legalities, and it's contractors, this area is still ripe for defining improvement initiatives. All such initiatives must begin with a re-defined supplier relationship, one where the contractor sees their fate as connected with that of the programs and projects in meeting some customer's requirements, a customer that lies outside the specific NASA enterprise, program or project that sources the work.

In this newly defined supplier relationship, information is integrated between contractors and programs to the advantage of meeting customer requirements, vs. suffering the loss of that customer (for the government meaning loss of relevance, funding, support, budget, science, or stakeholders). This is not easy. Traditionally, for example, the costs incurred by contractors, in detail, or the reliability metrics associated with suppliers, are kept close-in, as a form of competitive advantage, a way of negotiating the best terms – for the contractor. Traditionally as well, NASA fire-walls a large amount of information in dealing with contractors behind closed doors, even being required to by law, in order to also negotiate the best terms – for the government. While this tension can be seen as achieving a form of organic balance, with each parties motivation (the highest price, the lowest cost) seeming intuitively to yield the best result for all, it is actually an extreme form of losing sight of the customer, a paradigm being left behind in the management of modern, complex supply chains that seek to grow markets. Growing markets in the private sector can be equated in agency operations to growing or keeping support across multiple stakeholder levels, as well as within the simpler meaning of the term, as markets that grow are ones that benefit industry as well as NASA's future needs for services.

7. Returning to Myths, Misunderstandings, and Clarifications

Once again, considering the following statements:

I. High NASA overhead creates large fixed costs for NASA projects.
II. Most of NASA's budget goes to R&D
III. NASA has large fixed costs

These may be re-phrased now as:

I. High NASA overhead affects the amounts of funds available to NASA programs/projects in any zero-sum budget.
II. Most of NASA's budget is not R&D as much as product and technology development; R&D is usually under-funded, affecting later outcomes.
III. NASA' contractors in development, manufacturing and operations have large fixed costs relative to total costs and capacity.

8. Summary & Conclusions

The perspective that has been presented here has been that of data, definitions, and opportunities assuming a constrained fiscal environment that demands improvements across a diverse set of missions in the NASA Human Space Flight portfolio. These diverse missions complement each other, from agency support functions and efficient, institutional capabilities, to R&D at fundamental, generic levels or as product oriented advances, to formulation and development of new systems, to the recurring manufacture and operations of large integrated systems for space flight, vehicles, or outposts.

It is assumed here none of the basic roles NASA plays in Human Space Flight is more important than any other, or that a lack of resources somehow forces a choice to work on only a couple or a few of the roles. These roles are the integrated HSF enterprise. Support, R&D, product development, and recurring manufacture & operations are four parts to an enterprise geared to meet customer & stakeholder requirements.

Supply Chain Management opportunities, as perspectives and possibilities, have been presented here alongside data and definitions as a means to shift to an adaptable, more robust system of advances in human space flight. This is in response to uncertainties fiscal, technological, and cost, seeking practices that emphasize dramatic improvements in the flow of information, enabling flexible, adaptive flows of goods and services. In this way it’s possible to achieve ambitious outcomes even assuming these uncertainties will persist over the long term. The HSF system would have been designed around these uncertainties.

About the Author

Mr. Zapata has worked with NASA at the Kennedy Space Center since 1988. In that time he has held responsibility for Shuttle systems including the Shuttle External Tank and the Shuttle cryogenic propellant loading systems, as related flight and ground propulsion systems. Starting in the mid 90's he began work to translate the operations experience into improvements in flight and ground system designs for achieving improvements in ground operations processing from landing through launch, in all aspects from direct to in-direct operations. He participated in the Explorations Systems Architecture Study or "ESAS" contributing launch and landing ground operations cost estimates and integrating the KSC cost estimates into the ESAS life-cycle cost analysis.

Most recently Mr. Zapata is performing (1) strategic Constellation and NASA agency level future scenario analysis and (2) analysis supporting the Constellation Standing Review Board, by providing independent analysis of the KSC ground operations project.

Mr. Zapata looks forward to the day when access to space is safe, routine and affordable as a result of taking advantage of, quantifying and understanding the experience and lessons of past and current space transportation systems operations.

For related material see: http://science.ksc.nasa.gov/shuttle/nexgen/rlvhp.htm